Nuclear Physics-II

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Nuclear Reactions
Leacture No. 01

Nuclear Reaction:-

→ The Process in which the Properties of atomic nucleus changes once the projectile is hitted it.

Rutherford Perform

$\alpha + {}^{14}N \rightarrow {}^{17}O + \text{Proton}$

→ Cocksoft and Walton
↳ invented 1st Particle accelerated.

→ Nuclear reaction Collide a very fast moving electron.

$P + {}^{7}Li \rightarrow {}^{4}_{2}He + \alpha$

→ Lower Energy Reaction → 1 → 10 MeV Per nuclear
→ Moderate " "
→ Higher " "

Radiative Capture :-

→ If Projectile in a nuclear reaction is gamma ray Photon then it is Called Photon Capture.

$$a + X \rightarrow Y + b$$

(a → Projectile, X → target nucleus, Y → daughter nucleus, b → light Particle)

if $a = \gamma$ (Photon)

→ Nuclear reaction Can also be written as $X(a, b)Y$

Classification Of Nuclear Reaction :-

→ **Scattering Process :-** If $a = b$ then alternatively $X = Y$.

A nuclear Process is Said to be Scattered if $a = b$.

→ **Elastic Reaction :-** If Product Constitution i.e Y and b are in ground state then it is Called Elastic Reaction.

→ **Inelastic Reaction:-** If Product Constitution i.e Y and b are in excited state is inelastic Reaction.

→ **Knock out Reaction:-** There is another (3rd Particle) along with 'a' and 'b' is called Knock out Reaction.

→ **Direct Reaction:-** The reaction in which very few Particles of target interact with Projectile and the most remain Passive is called Direct Reaction.

→ **Compound Nuclear Mechanism:->**
→ Target nucleus share their energy levels with Projectile before the Projectile escaped out.
→ It Support Nuclear model.

→ Resonance Reaction:-

→ In which the incoming Particle form a Quasi bound state before the outgoing Particle ejected.

→ Transfer Reaction:-

A reaction in which the

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CONSERVATION LAWS IN NUCLEAR REACTION:-

(i) CONSERVATION OF CHARGE:-

→ Total charge is always conserved in every type of nuclear reaction.

Excample:- $^{10}B\ (\alpha, p)\ C^{13}$

OR $^{10}_{5}B + ^{4}_{2}He \rightarrow (^{14}_{7}N)^{*} \rightarrow ^{1}_{1}H + ^{13}_{6}C$

→ There are 7 protons initially, also 7 Protons in the Compound nucleus and in the Product of the reactants.

(ii) CONSERVATION OF NUCLEONS:-

The total no. of nucleons entering and leaving the reaction are always Conserved.

Excample:- IN $^{10}B(\alpha, p)^{13}C$, we find 14 nucleons at each stage of the reaction.

(iii) → **Conservation Of Mass And Energy**

In Nuclear Reaction niether K.E nor mass is Conserved by itself. But their total is always Conserved. This is because mass and energy are equivalent to each other by Einstein Equation $E = mc^2$.

(iv) → **Conservation Of Parity:-**

The net Parity before the reaction must equal the net Parity after the reaction.

(v) → Linear momentum, angular momentum, Spin and isotopic Spin are also Conserved in nuclear Reaction.

→ **Quantities Not Conserved:**

→ The magnetic dipole moment and electric quadropole moment are not Conserved during nuclear reaction.

→ These moments depends upon internal distribution of mass, charge and Current within the nucleii involved and are not Subject to Conservation laws.

NOTE :-

Isospin – isotopic Spin – isobaric Spin

→ It is a quantum number related to up ~~to~~ & down quark Content of the Particle. it is the Property that is characteristics of families of related Subatomic Particles differing Principally in the values of their electric charge.

→ Reactants
→ Products
→ Nucleons
→ Electric Qudrupole moment
→ magnetic dipole.

Nucleon:→ The nucleons are Particles that make up the atomic nucleus.

→ **Proton:→** Composed of two up & one down Quark.

→ **Neutron:→** Composed of two down & one up Quark.

→ **Electric Qudrupole Moment:→**

The departure of charge distribution from Spherical Symmetry gives rise to Quarupole moment.

PARITY:→ The quality of Sameness or equivalence is called Parity.

→ The Parity refers to the behaviour of a wave function under the inversion in Space.

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Q-Value Of Nuclear Reaction:-

→ The Q-value for a reaction is the amount of energy absorbed or released during the nuclear reaction. It can be determined from the masses of reactants and products.

i.e $$Q = T_f - T_i$$

OR $$Q = (m_f - m_i)c^2$$

Where T_i and T_f are initial and final Kinetic energy of reactants and products.

Exothermic OR Exoergic Reaction:-

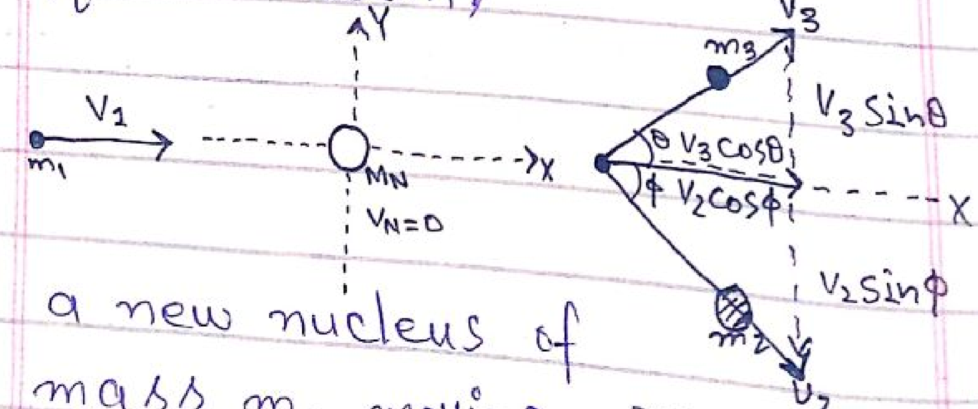
If $Q > 0$ ($m_i > m_f$ or $T_f > T_i$), the reaction is said to be Exoergic i.e in this case nuclear mass or binding energy is released as K.E of the final products.

Endothermic Or Endoergic Reaction

If $Q < 0$ ($m_i < m_f$ or $T_f < T_i$), the reaction is endoergic, the initial K.E is Converted into nuclear mass or binding energy.

Determination of Q-Value

Consider a Projectile of mass m_1 moving with velocity v_1 along x-axis is Collide with a nucleus of mass M_N which is initially at rest. After Collision,



a new nucleus of mass m_2 moving with velocities v_2 and new Projectile of mass m_3 moving with velocity v_3, Scattered at

angle of ϕ and θ respectively with original direction of Projectile.

→ Using law of Conservation of linear momentum in the Plans.

along x-axis

$$m_1 V_1 + M_N(0) = m_2 V_2 \cos\phi + m_3 V_3 \cos\theta$$

$$\Rightarrow m_2 V_2 \cos\phi = m_1 V_1 - m_3 V_3 \cos\theta \rightarrow (i)$$

along y-axis

$$0 = m_2 V_2 \sin\phi - m_3 V_3 \sin\theta$$

$$m_2 V_2 \sin\phi = m_3 V_3 \sin\theta \rightarrow (ii)$$

Square and adding eq. (i) & (ii)

$$m_2^2 V_2^2 \cos^2\phi = m_1^2 V_1^2 + m_3^2 V_3^2 \cos^2\theta - 2m_1 m_3 V_1 V_3 \cos\theta$$

$$+ \quad m_2^2 V_2^2 \sin^2\phi = 0 + m_3^2 V_3^2 \sin^2\theta + 0$$

$$m_2^2 V_2^2 = m_1^2 V_1^2 + m_3^2 V_3^2 - 2m_1 m_3 V_1 V_3 \cos\theta \rightarrow (iii)$$

Using K.E Relations

$$T_1 = \frac{1}{2} m_1 V_1^2, \quad T_N = 0, \quad T_2 = \frac{1}{2} m_2 V_2^2, \quad T_3 = \frac{1}{2} m_3 V_3^2$$

$$\boxed{2m_1 T_1 = m_1^2 V_1^2}, \quad \boxed{2m_2 T_2 = m_2^2 V_2^2}, \quad 2m_3 T_3 = m_3^2 V_3^2$$

Put in eq. (iii)

$$2m_2 T_2 = 2m_1 T_1 + 2m_3 T_3 - 2m_1 m_3 V_1 V_3 \cos\theta$$

$$m_2 T_2 = m_1 T_1 + m_3 T_3 - m_1 m_3 V_1 V_3 \cos\theta$$

at angle of $\theta = 90^\circ$

$$\Rightarrow \cos 90^\circ = 0$$

$$m_2 T_2 = m_1 T_1 + m_3 T_3$$

$$T_2 = \frac{m_1 T_1}{m_2} + \frac{m_3}{m_2} T_3 \rightarrow \text{(iv)}$$

As,

$$Q = T_f - T_i$$

$$Q = T_2 + T_3 - T_1$$

Using eq. (iv)

$$Q = \frac{m_1 T_1}{m_2} + \frac{m_3 T_3}{m_2} + T_3 - T_1$$

$$\boxed{Q = \left(1 + \frac{m_3}{m_2}\right) T_2 - \left(1 - \frac{m_1}{m_2}\right) T_1}$$

→ This is expression for Q-value of K.E.

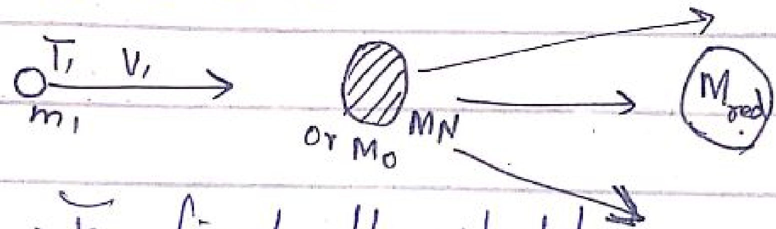
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THRESHOLD ENERGY

Define:- The minimum energy of Projectile (incident Particle) which will (used to) initiate an enedoergic Reaction.

Derivation:-



→ To find threshold energy we are using Centre of mass Co-ordinate System. For any Collision or reaction in Centre of mass Co-ordinate System, the linear momentum is always remains Conserved.

Let T_1 is K.E of Projectile in Centre of mass Co-ordinate system. The endorgic reaction is Possible if

$$T_1 \geq |Q| \longrightarrow (1)$$

Let Mred. is the reduced mass of incident Particle and target Nucleus.

Then,

$$M_{red} = \left(\frac{m_1 m_0}{m_1 + m_0}\right)$$

$$T_1 = \frac{1}{2} M_{red} V_1^2$$

$$T_1 = \frac{1}{2}\left(\frac{m_1 m_0}{m_1 + m_0}\right) V_1^2 \rightarrow \text{(ii)}$$

from eq. (i) and (ii)

$$\frac{1}{2}\left(\frac{m_1 m_0}{m_1 + m_0}\right) V_1^2 \geq |Q|$$

$$\frac{1}{2} m_1 V_1^2 \geq \left(\frac{m_1 + m_0}{m_0}\right)|Q|$$

where

$T_1 = \frac{1}{2} m_1 V_1^2$ is Called Threshold Energy.

i.e.

$$E_{th} \geq \left(\frac{m_1 + m_0}{m_0}\right)|Q|$$

$\Rightarrow$

$$E_{th} = \left(1 + \frac{m_1}{m_0}\right)|Q|$$

OR

$$\boxed{E_{th} = \pm Q\left(1 + \frac{m_1}{m_0}\right)}$$

Leacture No. 05

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TRANSMUTATION

Whenever a radioactive nucleus emitts nuclear radiation, it Converted into a nuclens of new element, This Process is Called Transmutation.

Types:-

(i) Natural Transmutation

It requires no external initiations. It is a Spontaneous Process.

Exp:→ The radiation emitted by elements whose $Z > 82$, and then Converted into new elements.

(ii) Artificial Transmutation

→ It requires some external Source, i.e a Projectile for the nucleus reaction. It is also Called induced or Stimulated Transmutation.

Types

(i) Transmutation By Photons

→The disintegration of atomic nuclei by the bombardment with high energy Photon (γ-rays) is cathode it is also Called ~~Photodis~~ Photo disintegration.

→ As rest mass of Photon is zero, So it transfer only its K.E to the target nucleus. This K.E Should be

K.E > B.E (binding energy) of the target nucleus.

→ For Photodisintegration the K.E of Photon is usually $\approx$ 10MeV

→This reaction is endothermic.

⇒ Exp.

(i) (γ, n) Photo reaction.

General Representation

$$\gamma + {}^{A}_{Z}X \longrightarrow \left[{}^{A}_{Z}C_n\right] \rightarrow {}^{A-1}Y + {}^{1}_{0}n$$

OR $\gamma + {}^{2}_{1}H \rightarrow \left[{}^{2}_{1}H\right]^{*} \rightarrow {}^{1}_{1}H + {}^{1}_{0}n$

(ii) (γ, P)

General Representation

$$\gamma + {}^{A}_{Z}X \rightarrow [{}^{A}_{Z}X]^{*} \rightarrow {}^{A-1}_{Z-1}Y + {}^{1}_{1}H$$

OR

$$\gamma + {}^{25}_{12}Mg \rightarrow [{}^{25}_{12}Mg]^{*} \rightarrow {}^{24}_{11}Na + {}^{1}_{1}H$$

(iii) $(\gamma, 2P, n)$ Photo reaction

General Representation.

$$\gamma + {}^{A}_{Z}X \rightarrow [{}^{A}_{Z}X]^{*} \rightarrow {}^{A-3}_{Z-2}Y + 2\,{}^{1}_{1}H + {}^{1}_{0}n$$

OR

$$\gamma + {}^{27}_{13}Al \rightarrow [{}^{27}_{13}Al]^{*} \rightarrow {}^{24}_{11}Na + 2\,{}^{1}_{1}H + {}^{1}_{0}n$$

(ii) TRANSMUTATION BY PROTONS

→ The Proton denoted by ${}^{1}_{1}H$ or P can be used as Projectile in nuclear transmutation.

EXP (i) (P, α)

General Representation

$$ {}^{1}_{1}H + {}^{A}_{Z}X \rightarrow [{}^{A+1}_{Z+1}X]^{*} \rightarrow {}^{A-3}_{Z-1}Y + {}^{4}_{2}He$$

$$ {}^{1}_{1}H + {}^{7}_{3}Li \rightarrow [{}^{8}_{4}Li]^{*} \rightarrow {}^{4}_{2}He + {}^{4}_{2}He$$

→ In Case of flourine

$$ {}^{1}_{1}H + {}^{19}_{9}F \rightarrow [{}^{20}_{10}F]^{*} \rightarrow {}^{16}_{8}O + {}^{4}_{2}He$$

(ii) ExP (P, n) Nuclear Reaction

General Representation

$$ {}^{1}_{1}H + {}^{A}_{Z}X \rightarrow [{}^{A+1}_{Z+1}X]^{*} \rightarrow {}^{A}_{Z+1}Y + {}^{1}_{0}n $$

$$ \rightarrow {}^{1}_{1}H + {}^{11}_{5}B \rightarrow [{}^{12}_{6}B]^{*} + {}^{11}_{6}C + {}^{1}_{0}n $$

(iii) ExP (P, γ) Nuclear Reaction

General Representation.

$$ {}^{1}_{1}H + {}^{A}_{Z}X \rightarrow [{}^{A+1}_{Z+1}X]^{*} \rightarrow {}^{A+1}_{Z+1}Y + \gamma $$

$$ {}^{1}_{1}H + {}^{12}_{6}C \rightarrow [{}^{13}_{7}C]^{*} \rightarrow {}^{13}_{7}N + \gamma $$

(iv) ExP (P, d) Nuclear Reaction

General Representation.

$$ {}^{1}_{1}H + {}^{A}_{Z}X \rightarrow {}^{A+1}_{Z+1}X \rightarrow {}^{A-1}Y + {}^{2}_{1}H $$

$$ {}^{1}_{1}H + {}^{7}_{3}Li \rightarrow [{}^{8}_{4}Li]^{*} \rightarrow {}^{6}_{3}Li + {}^{2}_{1}H $$

Leacture No. 06

May 18, 2022.

TRANSMUTATION BY DEUTRON

→ Deutron is the isotope of Hydrogen denoted by "d" or "${}^2_1H$" in nuclear reaction.

→ The deutron induced reaction are different then other induced nuclear reaction because charge distribution of deutron is not symmetric and having loosly bound structure.

→ In this reaction the Product Particles like P, n or α often appears in group having different energies.

★ General Expression of Deutron Nuclear Reaction:-

$$ {}^2_1H \rightarrow {}^A_ZX \rightarrow \left[{}^{A+2}_{Z+1}X\right]^* \rightarrow \begin{cases} {}^{A+1}_{Z}Y + {}^1_1H \\ {}^{A+1}_{Z+1}Y + {}^1_0n \\ {}^{A-2}_{Z-1}Y + {}^4_2He \end{cases} $$

Exp

(i) (d,p) Nuclear Reaction

General Expression

$${}^{2}_{1}H + {}^{6}_{3}Li \rightarrow [{}^{8}_{4}Li]^{*} \rightarrow {}^{7}_{3}Li + {}^{1}_{1}H$$

(ii) (d,n) Nuclear Reaction

General Expression

$${}^{2}_{1}H + {}^{A}_{Z}X \rightarrow [{}^{A+2}_{Z+1}X]^{*} \rightarrow {}^{A+1}_{Z+1}Y + {}^{1}_{0}n$$

$${}^{2}_{1}H + {}^{12}_{6}C \rightarrow [{}^{14}_{7}C]^{*} \rightarrow {}^{13}_{7}N + {}^{1}_{0}n$$

(iii) (d,T) Reaction

T → Tritium → ${}^{3}_{1}H$

$${}^{2}_{1}H + {}^{A}_{Z}X \rightarrow [{}^{A+2}_{Z+1}X]^{*} \rightarrow {}^{A+1}_{Z}Y + {}^{3}_{1}H$$

$${}^{2}_{1}H + {}^{7}_{3}Li \rightarrow [{}^{9}_{4}Li]^{*} \rightarrow {}^{6}_{3}Li + {}^{3}_{1}H$$

(iv) (d,d) Reaction

In this type both Projectile and the emitted Particle is deutron.

This reaction Proceeds in two steps.

Step: 1:

$${}^{2}_{1}H + {}^{2}_{1}H \rightarrow [{}^{4}_{2}H]^{*} \rightarrow {}^{1}_{1}H + {}^{3}_{1}H$$

This is unstable

Step: II

$${}^{2}_{1}H + {}^{2}_{1}H \rightarrow [{}^{4}_{2}H]^{*} \rightarrow {}^{1}_{0}n + {}^{3}_{2}He$$

TRANSMUTATION By α :-

→ Alpha is a helium nucleus denoted by "α" or ${}^{4}_{2}He$ in nuclear reaction.

→ The transmutation of α-Particle can emits P, n or α in group with different energies.

General Expression

$${}^{4}_{2}He + {}^{A}_{Z}X \rightarrow \left[{}^{A+4}_{Z+2}X\right]^{*} \rightarrow \begin{cases} {}^{A+3}_{Z+2}Y + {}^{1}_{0}n \\ {}^{A+3}_{Z+1}Y + {}^{1}_{1}H \\ {}^{A}_{Z}Y + {}^{4}_{2}He \end{cases}$$

Note :-

α must have sufficient energy to overcome the Coulomb's barriers of the target nucleus.

EXP

(i) (α, P) Reaction

$${}^{4}_{2}He + {}^{23}_{11}Na \rightarrow \left[{}^{27}_{13}Na\right]^{*} \rightarrow {}^{26}_{12}Mg + {}^{1}_{1}H$$

(ii) (α, n) Reaction

$$^{4}_{2}He + ^{14}_{7}N \rightarrow [^{18}_{9}N]^{*} \rightarrow ^{17}_{9}F + ^{1}_{0}n$$

(iii) (α, γ) Reaction

$$^{4}_{2}He + ^{9}_{4}Be \rightarrow [^{13}_{6}Be]^{*} \rightarrow ^{13}_{6}C + \gamma$$

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ENERGY LEVEL OF NUCLEUS

→ Like electrons in atom, the nucleons in nucleus are also exists in Shell and Corresponds to energy state also there is a state of lowest Energy level is called ground state and described Possible excited state for nucleus. A nucleus in the excited state will not remain in that state for infinite time but will de-excite the lowest energy state like electron in the excited state.

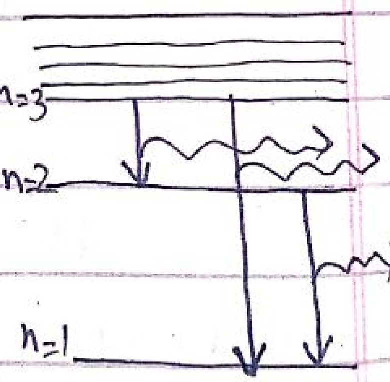
→ The electronic Shell in atom are in eV, while nucleus state are measured in Mev.

→ The de-excitation of electron in the Shell of an atom emits electromagnetic radiation having Shortest Possible wavelength is 10^{-10}m. i.e an X-ray Photon. While de-excitations of nucleons in nucleus emitts γ-rays for which it ≈ 10^{-12}m.

→ In atomic states the host Particle is electron while nuclear state Consists of nucleons (Photon + Neutron).

NUCLEAR ENERGY LEVL DIAGRAM

The energy level diagram of Nickle-60 is shown in fig. which Consists of Stack (or) of horizontal lines. Each represents the excited energy level of the nucleus. The difference in energy between ground state



and excited state is called excitation energy of that excited state.

- The excitation energy of ground state is taken as zero.
- The Probability of transition can be found when the time independent S.W.E. is solved by using Potential of the form of V+V'. Where 'V' is the Potential responsible for the Stationary state and V' is the Potential for transition b/w two excited states. The Probability of transition is given by Fermi-Golden Rule.

$$\lambda = \frac{2\pi}{h} | V'_{fi} | f(E_F)$$

Where,

$f(E_F)$: is the density of final state.

Types Of Nuclear Energy States:

Generally Nuclear states are divided into three regions based on rays of energy.

Low energy Level → 2 MeV

Moderate → 2 MeV to 6 MeV

High → above 6 MeV

Bound Energy Level

The higher Energy level in which nucleus de-excited to ground state by the emission or γ-ray or by the internal Conversion Process. In this case the excitation energy is not sufficient to emit the Particle like Proton, α-Particle etc.

Virtual Energy Level

In this case, the excitation

energy is Suppicient to emit the Particles.

→ Virtual energy level may refer very Short lives, unabsorable quantum state or a real but unstable state.